

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/269487773>

Cognitive Foundations of Musical Pitch Carol L. Krumhansl

ARTICLE *in* MUSIC PERCEPTION · JULY 1992

Impact Factor: 1.63 · DOI: 10.2307/40285567

READS

43

1 AUTHOR:



[Robert O. Gjerdingen](#)

Northwestern University

24 PUBLICATIONS 205 CITATIONS

SEE PROFILE

From: *Music Perception* 9 (1992): 476–492.

Carol L. Krumhansl, *Cognitive Foundations of Musical Pitch*. New York: Oxford University Press, 1990, 307 pp. [Oxford Psychology Series, No. 17]

Gracie Allen, queen of the comedic *non sequitur*, once appeared as soloist in a novelty piano concerto. Before the music began, the conductor, in the role of straight man, publicly coached her to play an ascending scale in the tonic key: *do, re, mi, fa, sol, la, si, do*. He then returned to his podium and gave the downbeat to the orchestra. Gracie sat and waited until the moment came for her solo. The conductor gave her the cue; she moved confidently up the scale and jarringly overshot the final *do* by a half step. The audience began to laugh and continued laughing as time and time again Gracie would receive her cue, charge dutifully up the scale, and hit a new but equally awful last note. Finally, as if by accident, she landed on the long-awaited *do*. The audience applauded, the conductor cut to the cadence, and the triumphant Gracie took a bow.

Jokes live or die by how well they play upon an audience's knowledge and expectations. Allen's piano-concerto routine, broadcast to a mass American audience, risked a sponsor's money and a famous comedienne's reputation on ordinary people knowing the right and wrong notes that might follow the context of an incomplete ascending major scale. The fact that the joke worked, and was in fact very funny to thousands of listeners, indicates that knowledge of what does and does not fit in that musical context is clear and widely held. If, as it would seem, the members of an audience invoke this knowledge automatically, perhaps continuously, then it forms an integral part of their musical experience.

Carol Krumhansl, in a book destined to become a landmark in the psychology of music, summarizes a decade of innovative experiments designed to explore the knowledge that listeners bring to music. The first of these studies, and one

characteristic of her method, chose as its object the very type of knowledge that Gracie Allen exploited for comedic effect:

We [Krumhansl & Shepard, 1979] observed that when an “incomplete” scale is sounded, such as the successive tones C, D, E, F, G, A, B, this creates strong expectations about the tone that is to follow. The tonic itself, C, is heard as the best completion, and it seemed to us that this was largely unaffected by whether the tone C was in the octave next to the penultimate B, or in some other octave. Other tones complete the sequence somewhat less well, and the degree to which this was the case appeared to be a function of the musical relationship between the final tone and the tonic implied by the incomplete scale. This, then, suggested that a way to quantify the hierarchy of stability in tonal contexts would be to sound incomplete scale contexts with all possible tones of the chromatic scale (which we call “probe tones”), and ask listeners to give a numerical rating of the degree to which each of the tones completed the scale.

By their responses, listeners with little or no musical training seemed to equate “completion” with simple proximity to the expected last tone. Tones close in pitch to the last tone of the preceding scale were judged as better completions than tones further away. This was true for either ascending- or descending-scale contexts. Listeners with more musical training, however, showed a different pattern of responses. For them, it would seem that the tonal relationship of the probe tone to its preceding context played a strong role in judgments of completion. After a C-major context, for example, these listeners judged F \sharp a far worse completion than G, even though both pitches are equidistant from the last tone of a scalar context (ascending: B₃ to F \sharp ₄ = seven semitones; descending: D₅ to G₄ = seven semitones). Effects of pitch proximity were not completely absent from these responses. But the clear indication that musically trained listeners were applying a subtler metric to their estimations of completion warranted repeating and refining the experiment to eliminate the effects of proximity.

The revised probe-tone experiment (Krumhansl & Kessler, 1982) addressed all the obvious shortcomings of the earlier study. It now included a richer set of contexts. Listeners heard, at various times, major scales, minor scales, tonic triads, or prototypical chord progressions ending on the tonic (IV-V-I, ii-V-I, vi-V-I). The new study accomplished a sharp reduction in the effects of pitch proximity. The researchers substituted complete scales for the earlier incomplete scales. And they used specially synthesized tones (Shepard tones) designed to attenuate the perception of a pitch's specific octave location. Since detecting pitch proximity appeared as a likely strategy for the musically untrained listeners in the earlier study, the new study limited itself to listeners with extensive musical training. At the same time, it excluded those with significant schooling in music theory so as to lessen the influence of traditional modes of musictheoretical explanation. The new study guarded against any hidden effects of absolute pitch perception by giving listeners contexts based on different key centers. And finally, it undertook the full panoply of those procedural safeguards and statistical checks that one has come to expect from rigorously controlled experiments.

The 10 listeners in this study responded to each probe by rating, on a scale from one to seven, how well the tone fit with the preceding context ("completion" no longer served as a meaningful measure inasmuch as the contexts were already complete). Figure 1 shows the results averaged for probe tones following the contexts of triads and chord progressions. In both major and minor contexts, the tonic pitch received the highest rating, the tonic triad's two other tones received the next highest ratings, and the remaining tones of the diatonic scale all received ratings higher than those registered for any nondiatonic tone. Clearly these ratings echo the relative degrees of stability traditionally ascribed by music theorists to each semitone in the context of a major or minor key. (In classical music, the common linkage between melodic contour and pitch inflection for the variable sixth and seventh degrees of the

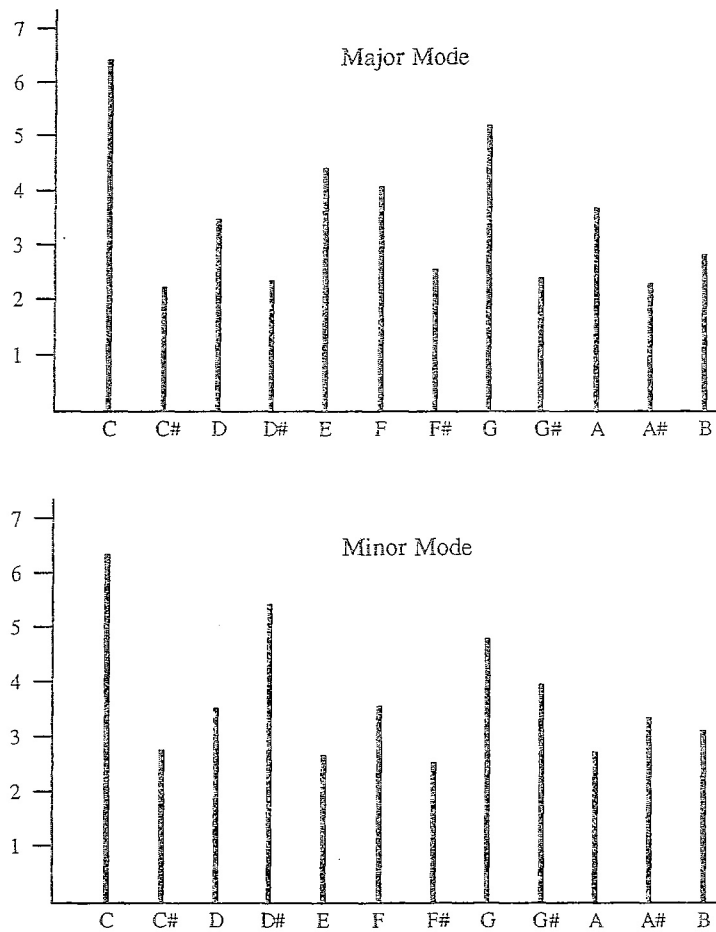


Fig. 1. Ratings for probe tones following a single tonic triad or a three-chord sequence ending on a tonic triad (redrawn from Krumhansl & Kessler, 1982).

minor mode precludes an unqualified determination of stability for those tones. As Krumhansl convincingly argues in a different context, a graph like Figure 1 cannot adequately represent such order-dependent relationships.)

With a class of about a dozen graduate music students, several of whom are musicians of great accomplishment, I conducted an informal replication of the ascending-scale, probe-tone experiment. Twelve times I played a complete, ascending C-major scale at a brisk tempo on the classroom piano, following each

scale with one of the 12 chromatic pitches played pseudo-randomly within a four-octave range. The students were given no practice sessions, there was only one presentation of each chromatic pitch, responses were on a scale of 1 to 10 instead of 1 to 7, there were doubtless unintended effects of pitch proximity and contour, and yet the average ratings for the class matched those of Figure 1 to a surprising degree. The correspondence may, of course, have been coincidental—a fortuitous alignment of several poorly controlled factors. But it may also indicate that Krumhansl's results are so robust that they survive even the most cavalier protocols, so robust that—much as Gracie Allen and her sponsor did—you can take them to the bank.

The ratings profiles of Figure 1 become both a point of departure and a recurring frame of reference for many of the book's subsequent discussions. As a point of departure, the ratings profiles can be hypostatized as distillations of the sense of major and minor tonality—as images of any major or minor key center expressed in the form of a 12-component vector. Because each such vector is a precise mathematical entity, the degree of similarity or difference between any pair of vectors can be precisely quantified. Instead of just saying that C major is close to G major, one can say that the ratings profile for C major and that for G major have, on a scale from -1.0 to +1.0, a correlation of .5910. Exactly the same high correlation exists between C major and F major. By contrast, the ratings profile for C major and that for E \flat minor have a low correlation of - .6532. And exactly the same low correlation exists between A major and C minor, F major and A \sim minor, and any other similarly related pair of keys (Krumhansl lists the correlation as -.654 instead of - .6532, a difference probably attributable to an accumulation of rounding errors).

Computing the correlations between the ratings profiles of all possible pairs of major and minor keys produces a matrix of similarity measures. The book relates how Krumhansl and Kessler (1982) used an algorithm for multidimensional scaling to transform this matrix into a spatial representation of inter key distance.

The derived representation specifies the location of each key as a point in a four-dimensional space. Two of these dimensions correspond to the circle of fifths (C, F, B \flat , E \flat , etc.) and two correspond to a circle of alternating major and minor thirds (g, E \flat , c, A \flat , f, D \flat , etc.). A rough sense of interkey distance can be estimated from a visual integration of these two circles into a torus (a doughnutlike surface in which one circle is the doughnut and the other is its cross section). But the true results are best evaluated only in numerical form.

The book lists the spatial coordinates of each key but not the interkey distances themselves, so readers who wish to convert the former into the latter may need a pocket calculator and the Euclidean distance formula:

$$distance(Key_1, Key_2) = \sqrt{(a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2 + (d_2 - d_1)^2}.$$

Here the variables a , b , c , and d stand for the values of dimensions 1–4 as listed on page 42. Computed by this method, distances range from a minimum of .649 (for keys related as relative major and minor) to a maximum of 1.996 (for major keys a tritone apart). The keys situated the shortest distance from C major are the very ones musicians traditionally describe as close to that key: A minor (.649), G major (.861), F major (.861), E minor (.863), C minor (.931), and D minor (1.065). Keys like B \flat major and D major are moderately distant (both 1.348), while keys like B major (1.800) or E \flat minor (1.892) are at the outer fringe. The musical plausibility of the general rank order of these interkey distances seems evident. The magnitudes of the distances, however, stem entirely from mathematical operations, not perceptual experiments. Thus one should not conclude that, judged from the reference point of C major, people perceive E \flat minor (1.892) to be about three times more distant than A minor (.649). And Krumhansl herself is careful to point out some indications that perceived interkey distances are not symmetrical in the way required by this spatial

model. That is, the perceived distance from A minor to C major might be different from that from C major to A minor.

The ratings profiles of Figure 1 are also used as a point of departure for an algorithm designed to determine the key of all or part of a musical composition. The premise behind the algorithm is simple: If one can determine the salience of each of the 12 semitones within a selected passage of music, then one can take the resulting 12-component vector of salience and correlate it with the ratings profiles of all major and minor keys. The ratings profile with the highest correlation ($\max[r_i]$) determines the key. For the initial applications of this key-finding algorithm, Krumhansl (working with Mark Schmuckler) equated salience with the total duration of each chromatic pitch within the musical passage. In a study of just the first four tones of preludes by J. S. Bach, Shostakovich, and Chopin, the algorithm did extremely well in determining the correct key in the Bach, fairly well in the Shostakovich, and not particularly well in the Chopin preludes. Given the limited information contained in only a few tones, the algorithm's overall performance was excellent and equals what might be expected from a competent listener. In a second study of Bach and Shostakovich fugue subjects, longer contexts were examined, although the algorithm again often needed only a few tones to identify the correct key. And in a third study the algorithm was used to attempt a measure-by-measure tracking of changing key references in the C-minor prelude from Book 2 of Bach's *Well-Tempered Clavier* (WTC).

The key of the C-minor prelude is indisputably C minor. The same cannot be said for each moment within the prelude. Moreover, musicians may disagree about the tonal orientation of various passages, especially passages forming transitions between more strongly delineated key centers. So Krumhansl and Schmuckler first obtained analyses of key references in this prelude from two music theorists. Their analyses were not in complete agreement, but the differences between them were

understandable. What was a primary key reference to the one theorist was a secondary reference to the other, and vice versa. A comparison of the theorists' judgments with the measure-by-measure results of the keyfinding algorithm pointed up deficiencies in the algorithm's performance. To improve it, Krumhansl and Schmuckler enlarged the context for each measure to include one previous and one subsequent measure, and weighted the current measure two-to-one over the outlying measures. In so doing, they created a very rough approximation to the bell-shaped, moving temporal window used in many signal-processing applications. In both contexts the need to integrate as large a temporal span as possible confronts the opposing need to assign each result to a single moment in time. A moving, bell-shaped window onto the data accommodates both needs.

The opening of Bach's C-major prelude (*WTC*, Book 1), shown in Figure 2 (Krumhansl's Fig. 4.5 notates this fugue incorrectly as beginning with three sixteenth notes), illustrates the particular strengths and weaknesses of the key-finding algorithm. Krumhansl notes that the algorithm determines the correct key after only the first two tones. Not only is this quite a remarkable achievement, a feat of musical intuition reminiscent of the most talented contestants on *Name That Tune*, but it understates by half the algorithm's potential. Two tones seem to be required because, when presented with just the first tone (C_4), and when limited to three significant digits in computing correlations, the algorithm can narrow the likely

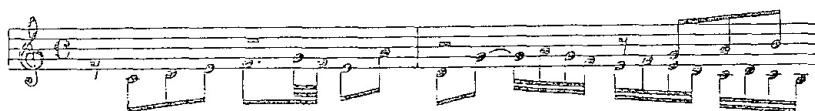


Fig. 2. The opening subject of J. S. Bach's C-major fugue from *The Well-Tempered Clavier*, Book 1 (1722).

keys down to C major (.684) and C minor (.684) but cannot choose between them. Yet had the algorithm been allowed four significant digits, it would have picked C major (.6844) over C minor (.6841) at the outset. For this fugue subject, one of the 14 out of 48 that begin on a major-mode tonic, the algorithm gives a correct answer after just one note, though this also means that for 34 of the fugue subjects it gives a wrong answer after just one note.

The second tone of this fugue enters a whole step above the first tone. Any melody beginning with an ascending whole step (where the second tone's duration does not exceed that of the first tone) will correlate most highly with the major key centered on the first tone. Thus in Figure 2, C₄-D₄ leads the algorithm to select C major, as reported. Yet among these fugue subjects, an initial ascending whole step is 50% more likely *not* to be in the major key of the first tone—some will be *do-re* in minor and others will be *sol-fa* in major. When the third tone of the subject enters,

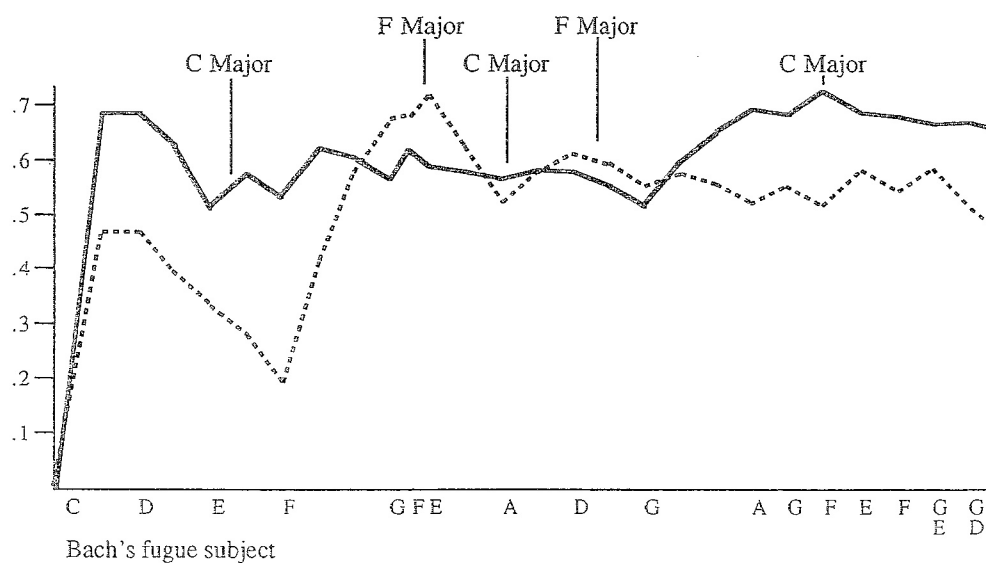


Fig. 3. For the musical excerpt shown in Figure 2, the moment-by-moment rivalry between C major and F major as it would be calculated by Krumhansl and Schmuckler's key-finding algorithm.

E_4 , it merely reinforces the algorithm's selection of C major. By contrast, the entry of the subject's long fourth tone, F_4 , forces the temporary selection of F major. F major is not a mistake; Bach sometimes harmonizes the subject's fourth tone as a tonic. The algorithm's ability to track the moment-by-moment "intervallic rivalry" (Butler, 1989) between C major and F major is, in fact, one of its great strengths. In Figure 3, I have indicated how the algorithm would rate these two keys as the subject progresses. Notice that F major overtakes C major not at the onset of F_4 but only after it becomes the longest tone in its context. This is musically sound. The subsequent rapid flip-flops between C major and F major, however, seem musically suspect.

Part of the problem is the lack of a definition of musical salience that integrates duration with rhythmic relationship, metrical placement, melodic contour, dynamics, consonance, and stylistic knowledge. Krumhansl discusses how some of these musical features could give the algorithm better input. Part of the problem lies in the algorithm reflecting a theory of key finding, not one of key selecting. More subtle criteria for evaluating potential key centers might give the algorithm better output. And finally, part of the problem may stem from the model's basic design. That design—a linear correlator feeding into a nonlinear key selection function ($\max[r_i]$)—can produce wildly unstable output unless there are stabilizing feedback paths from the key-selecting stage to the correlator. In an unpublished paper, Anne Haight informally tested musicians to learn what key center they would attribute to short melodies specially composed to correlate well with both the C major and A minor ratings profiles. Some musicians heard A minor, some heard C major, and a few heard some third key. In each case, the musicians appear to have perceived one key and not the other. The percept did not oscillate rapidly between the two keys as it might have had a bald $\max[r_i]$ been the key-selecting function.

In discussing ways to improve the algorithm, Krumhansl downplays the role

of meter. She observes that consonance and dissonance, for example, need not correlate strongly with weak and strong beats. She also observes that rhythmic and tonal patterns have a measure of independence. While these points are true, they have little to do with meter's role in music perception. A simple metrical filter of the type proposed in Gjerdingen (1989), for instance, would substantially improve the algorithm's analysis of the fugue subject by preventing rapid oscillations between the two keys (see Figure 4). So would a consideration of dynamics, a parameter vitally important in real music but sadly almost never discussed. As Narmour (1990) argues at length, we need to consider a number of parametric scales simultaneously.

The ratings profiles shown earlier in Figure 1 are also used as a frame of reference for the interpretation of results from other experiments. A study of the perceived relations between the two tones of simple melodic intervals, for instance, gave results that suggest a strong contextual effect on the tones' positions within the ratings profiles. The experiment was conducted along lines similar to the

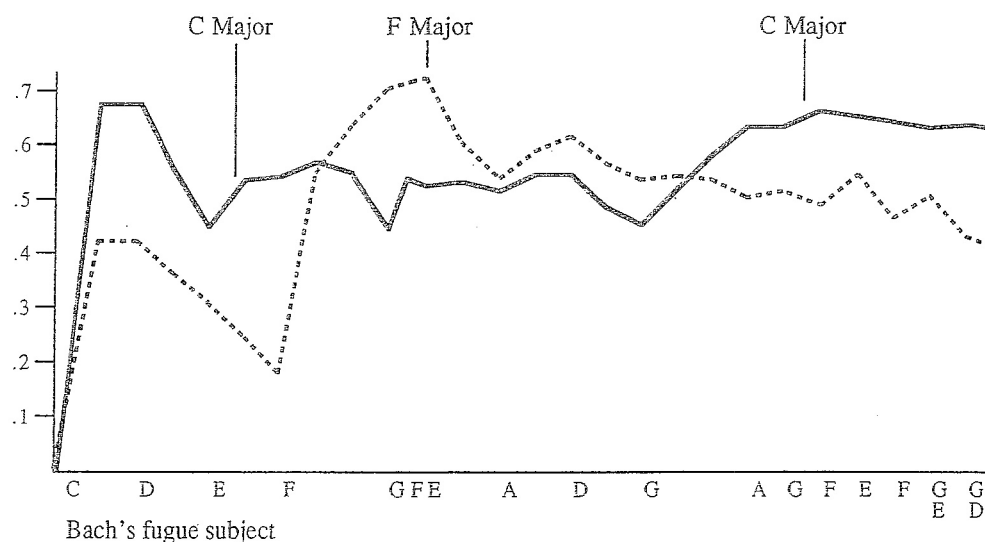


Fig. 4. For the musical excerpt shown in Figure 2, output from Krumhansl and Schmuckler's key-finding algorithm as altered by a metrical filter (cf. Fig. 3). Events occurring at metrically stronger locations are weighted more strongly than events occurring at metrically weaker locations.

Krumhansl and Kessler (1982) probe tone studies. Tonal contexts were followed by all possible pairs of distinct Shepard tones, and listeners were asked to rate, on a scale of one to seven, how well the second tone followed the first tone. In the context of C major, the results show that the ascending whole step D-E elicits an average rating of 5.25 whereas the same whole step descending, E-D, elicits a rating of only 4.58. Is the difference due to the direction of the interval? Apparently not, since a similar whole step, G-A, has a lower rating when ascending (5.00) than when descending (5.42). In both these cases, and in the results in general, the higher rating corresponds to the interval whose second tone has the higher position in the ratings profile of Figure 1.

Krumhansl prefaces the discussion of this experiment with a review of geometrical representations of musical pitch relationships. There is quite a history of these grids, helices, toroids, cones, and sundry other graphs. She points out that they necessarily depend on distances being symmetrical. For example, the distance formula presented earlier requires that the distance from key x to key y be identical to the distance from key y to key x . Clearly the above results for relations between pairs of tones are asymmetrical, suggesting that a geometrical model is inappropriate in this case. As an alternative, she presents the analysis by Tversky and Hutchinson (1986) of major-mode tone-pair ratings from Krumhansl and Shepard (1979), a pre-Shepard-tone version of the experiment just discussed. As shown in Figure 5, this “nearest-neighbor” analysis attempts to define *what* is closest to *what*. For instance, G \sharp is closest to A, A is closest to G, and G is closest to C \flat . Note that these relationships are asymmetrical—G \sharp may be closest to A, but A is not closest to G \sharp (the values alongside each pitch give an index of asymmetry, with high values indicating more asymmetrical relationships).

Tversky and Hutchinson’s analysis is consistent with the way musicians talk about tones: G \sharp “goes” or “leads” to A, B is the “leading tone” in the key of C, etc.

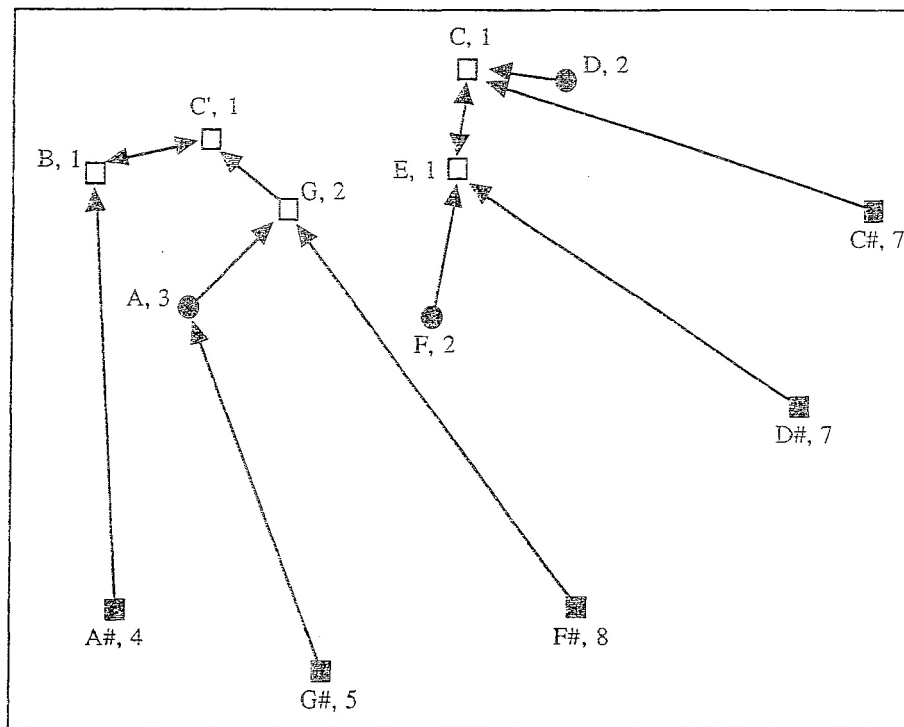


Fig. 5. Tversky and Hutchinson's nearest neighbor analysis of data from probe-tone pairs in Krumhansl (1979, redrawn from Tversky & Hutchinson, 1986). Arrows point to a tone's nearest neighbor. The number next to each pitch name indicates a reciprocity value. The higher the number, the more asymmetrical the relationship to that pitch's nearest neighbor. White squares represent focal pitches, black squares represent outlying pitches.

It is consistent with the formalization of these intuitions given in Sadai (1990), with the notion of embedded pitch alphabets presented in Deutsch and Feroe (1981) and expanded by Lerdahl (1988) as "tonal pitch space," and with the melodic anchoring principles of Bharucha (1984). Rather than showing a constellation of discrete entities, the nearest-neighbor analysis presents a connected network of musical interrelationships. It distinguishes between focal pitches and outlying pitches. Indeed, it presents important aspects of a *tonal hierarchy*. The emphasis is intended to point up a distinction between the nearest-neighbor analysis and the

ratings profiles of Figure 1, which Krumhansl terms “tonal hierarchies.” A simple list of 12 values may represent a set or a vector, but not a hierarchy. The “hier” in hierarchy derives not from “higher and lower” on a continuum but from “priest” and the stratified chain of command within priestly society. In evaluating a ratings profile, we bring with us the knowledge that C is the tonic of the C-major profile, that G is its dominant, that B is its leading tone, or that F \sharp is nondiatonic and a leading tone to G. But this knowledge is clearly extrinsic to the information represented in the profile itself.

Krumhansl further develops the important idea of contextual asymmetry in reference to a series of studies on musical memory. She formalizes three principles of how tonal context affects pitch relationships. The first, *contextual identity*, maintains that the psychological sense of identity between a tone at one moment in a melody and the same tone at a later moment *increases* in proportion to the tone’s rank in the tonal hierarchy. The second principle, *contextual distance*, holds that the psychological distance between two tones (averaged across both possible orderings of the tones) *decreases* in proportion to the sum of their ranks in the tonal hierarchy. And the third principle, *contextual asymmetry*, asserts that the difference in the psychological distances between one ordering of two tones and the reverse ordering *increases* in proportion to the magnitude of the difference between the tones’ ranks in the tonal hierarchy. These principles may serve as aids in evaluating the numerous effects of tonal context in both past and future psychological studies of musical cognition.

Contextual asymmetry is not, however, the sole reason for questioning the appropriateness of spatial models. Consider the arguments of the French anthropologist Pierre Bourdieu (1972/1977) against abstract geometrical models of cultural relationships and practices:

The logical relationships constructed by the anthropologist are opposed to “practical” relationships—practical because continuously practised, kept up, and cultivated—in the same way as the geometrical space of a map, an imaginary representation of all theoretically possible roads and routes, is opposed to the network of beaten tracks, of paths made ever more practicable by constant use. . . . A map replaces the discontinuous, patchy space of practical paths by the homogeneous, continuous space of geometry. . . . [A geometrical space creates] *ex nihilo* the question of the intervals and correspondences between points which are no longer topologically but metrically equivalent. . . . The gulf between this potential, abstract space, devoid of landmarks or any privileged center—like genealogies, in which the ego is as unreal as the starting-point in Cartesian space—and the practical space of journeys actually made, or rather of journeys actually being made, can be seen from the difficulty we have in recognizing familiar routes on a map or town-plan until we are able to bring together the axes of the field of potentialities and the “system of axes linked unalterably to our bodies, and carried about with us wherever we go,” as Poincare puts it, which structures practical space into right and left, up and down, in front and behind.

Modulations, for example, are musical paths between key centers—well-beaten tracks between familiar locations. When keys are represented as points in an abstract four-dimensional space, all paths suddenly become possible. Krumhansl’s Figures 4.7–4.12 plot the movement of key references in Bach’s C-minor prelude as a continuous line moving freely on the surface of a toroid. But what is the meaning of, as in her Figure 4.7, a line that begins west of C minor, moves south southwest toward G minor, but halfway there takes a 90-degree turn toward the east southeast in the general direction of f1, major? Bach’s prelude begins in C minor, not west of C minor. The abstraction of the geometrical representation conceals the musical impossibility of Bach being off the path. Furthermore, the decision to make the measure the unit of analysis for the key-finding algorithm is musically arbitrary. The modulatory path in this prelude often turns at mid-measure. So the ability of the

representation to plot an arbitrary location serves to conceal the musically arbitrary status of those locations.

Space does not permit an adequate summary of the full range of issues taken up in the course of this book. There are innovative discussions of harmony, temporal organization, 12-tone music, polytonality, octatonicism, Balinese music, Jairazbhoy's model of the North Indian *that* system, modulation, tone distributions in various repertoires, abstract properties of real and imagined scales, and many of the subsidiary issues raised in connection with these subjects. One can hardly imagine anyone concerned with music perception who would not find these topics of great interest.

Gracie Allen's audiences responded effortlessly to the manifest reality of the probe-tone ratings profile. My students derived the major-mode profile in an experiment lasting scarcely more than 2 min. Krumhansl experimentally established the major- and minor-mode profiles in the late 1970s, and others have replicated her findings many times since. The profiles themselves are not a problem. But explaining them is an intellectual challenge of considerable complexity. Readers of this journal may recall the vigorous exchanges between Butler (1989, 1990) and Krumhansl (1990) on the general subject of interpreting these profiles. In the present book, Krumhansl again addresses many of the objections raised against her view that the profiles are evidence of "experimentally quantified hierarchies" of musical "stability or structural significance" (p. 210). She investigates the correlations between, on the one hand, the profiles and various indices of musical consonance, and, on the other hand, the profiles and various statistical analyses of tonal music. Both sets of correlations are significant and neither set is unproblematical.

Correlations with statistical analyses of pitch distributions in tonal music are hampered by the difficulties in compiling such statistics. All the contextual effects that Krumhansl describes so well conspire to put into question the meaning of

counting all the C#s in a composition as members of the same category. Yet this is precisely the approach taken in Youngblood (1958). And the more recent sampling approach of Knopoff and Hutchinson (1983), with its recognition of explicit changes of key signature, still does not factor in simple modulation, much less the transient, multiple key references detailed in Krumhansl's discussion of modulation. I share Krumhansl's belief that people initially learn to understand music in part through their sensitivity to statistical regularities in the music they hear. But I suspect that the entities making up those statistical regularities are relational in nature—intervals, rhythms, and contours rather than individual pitches. As she herself says, “music perception is a dynamic process in which each event is encoded in terms of its relations to other events in its temporal context” (p. 210).

Correlations with measures of consonance are complicated by the fact that several of the world's major musical traditions, including our own, have long-standing theoretical traditions that equate musical consonance with musical propriety or naturalness. These cultures have used the mathematics of simple integer ratios to “rationalize” their tonal systems. Thus a listener who rates probe tones according to a tonal hierarchy and one who rates them according to their consonance with the implied tonic may, especially for the classical traditions of European and Indian music, give similar responses. Krumhansl points out that Parncutt (1987), in an extension of the work of Terhardt, Stoll, and Seewan (1982a, 1982b) on virtual-pitches in measures of pitch salience, produced a psychoacoustically based profile of what he terms “tone prominence” that correlates extremely well with the probe-tone ratings profiles (.986 with major, .941 with minor). The psychological validity of his method, which as shown in Parncutt (1988) involves some manual tweaking of coefficients in order to get the desired result, and which uses a slightly different context of chord progressions, is yet to be fully established. Nevertheless these extremely high correlations, higher than those for any other measure of consonance

or for any other statistical analysis of tone distributions (excepting the peculiar correlation with Hughes [1977]), warrant further study.

Krumhansl's book never directly treats the question of whether music has a syntax. Perhaps the question is specious. But I wonder if there are not some indications that various results are less syntactical, and hence less cognitive, than suggested. Take the case of the minor mode. Krumhansl notes that the huge chord census of Budge (1943) shows an amazing correlation of .997 between the distribution of *Stufen* (the scale-degree numbers of diatonic chordal roots, i.e., IV, vii, etc.) in major and minor keys. As Krumhansl comments, "the tabulated results support the view that corresponding chords in the different modes are treated as equivalent in compositions of this period [the 18th and 19th centuries]" (p. 180). Musical syntax is largely unaffected by a simple change from major to minor. But almost without exception, probe-tone results for minor chords and minor keys are in some way less intelligible, more problematic than for major.

Take, for example, the harmony experiment with major, minor, and diminished chords as probes (Chap. 7). In the contexts of major or minor keys, listeners rated any major chord higher than *any* minor chord (save the minor tonic in the minor context). Or take the basic minor ratings profile itself (see Figure 1). Even though the three-chord contexts (e.g., iv-V-I) employed what I presume were major dominant chords (making the leading tone, B \sharp , the contextual scale tone), the ratings for B \flat , were higher than for B \sharp . B \flat pt" however, fits in very well as a consonance with E \flat . Krumhansl notes a possible effect of the relative major key, E \flat , in relation to the high rating for the tone E \flat in the minor-mode profile of Figure 1. If one substitutes zeros for the five lowest ratings in both major and minor profiles, thus eliminating the fact that the minor profile has consistently higher ratings for nondiatonic tones, then the correlation between C-minor and E \flat -major jumps to .9020, a very high value. Yet the tonal hierarchy of C minor cannot just be that of E \flat major shifted slightly off center.

The tonal hierarchy of C minor, defined broadly, ought to correlate best with that of C major. The word “tonality” (*tonalité*) was coined in reference to the “*chordes tonales*,” the scale degrees I, IV, and V (Castil-Blaze, 1821). These are the degrees untouched by changes between major and minor.

Musical syntax is important in defining a key. Take, for example, the disappointing results of probe tones following the IV–V sequence of triads (in the key of C major, the F-major and G-major triads). This two-chord sequence is an unambiguous determiner of the key of C major. Indeed, it is one of the prototypical indicators of that key center. Yet the ratings of probes played after this context have a correlation of only about .650 with the standard C-major profile, as judged by Krumhansl’s Figures 9.2, 9.4, 9.5, and 9.9 (Figure 9.10 is slightly misdrawn). While moderately high, it is no better than the correlation between C major and A minor. Moreover, this IV–V context had the potential to counter some questions about whether the ratings profiles of Figure 1 might not reflect certain effects of short-term memory. For example, since the contexts used to produce the profiles of Figure 1 all sounded a C-major triad immediately before the probes, perhaps the still-fresh memory of that sound affected the ratings profiles. The IV–V sequence creates the strong syntactical expectation of a C-major triad without actually sounding the triad. So the failure of probe-tone ratings to have correlated as highly with the C-major profile when the physical sound of a C-major triad was absent leaves many issues unresolved. Perhaps similar short-term memory effects partially explain the probe-tone results of West and Fryer (1990). The contexts in their experiment were pseudo-random sequences of the seven diatonic scale degrees. For this context, Krumhansl and Schmuckler’s key-finding algorithm will select C major as the key, with A minor being the second choice. Yet in response to various orderings of the seven scale degrees, listeners variously identified tonics on C, F, G, or E. Other recency effects in probe-tone studies are noted in Janata and Reisberg (1988).

In a work of this complexity and scope, there are bound to be a few slight errors. The octatonic scale, for instance, seems to have proved troublesome. The scale “can be described as the combination of two diminished” *seventh chords*, not “triads” (p. 229). And although “Messiaen (1944) called it a mode of limited transposition,” the assertion that “there are just two octatonic scales” (p. 277) makes it more limited than even Messiaen envisioned. There are, in fact, three octatonic scales. I also noticed a tendency to postdate, inadvertently, the citations from historical treatises. For example, Helmholtz’s epochal work appeared in 1863 but is cited here (and elsewhere) from the second edition of Ellis’s translation (1885, orig. trans. 1875), a curious accident of the ubiquity of Dover reprints. Schoenberg’s famous *Harmonielehre* (“Theory of Harmony”) is cited as 1922, the date of its third revised edition, rather than 1911, because Carter’s 1978 translation used the third edition as its source. And Schoenberg’s second lecture on “Composition with Twelve Tones,” cited as “originally published 1948” is only *circa* 1948, being a then unpublished typescript of a lecture whose original form dates perhaps back into the thirties. Somewhat in reverse, Reger (1903) was published in Leipzig—the “Kalmus Publication No.3841” is a later reprint. One might quibble with a nominally British press placing “sic” after A. J. Ellis’s Victorian-era use of “shew” (= show, p. 54). Imagine a similar editing of the Book of Ruth: “Whither [sic] thou [sic] goest [sic]. . . .” These are, nevertheless, exceedingly minor blemishes that do not mar the fine way the book has been edited. Perhaps only the lack of an adequate subject index will detract from the book’s utility as a reference.

Krumhansl’s work—always impressive and never more so than in this book—leads us to confront our basic ideas about music and music perception. The question of whether probe-tone ratings profiles reflect musical consonance or statistical distributions of tones is one of those eternal questions about the relative importance of nature versus nurture. And the problems of reconciling static ratings

profiles with dynamic contextual asymmetries echo the great nineteenth-century tensions between Riemann's assertion of universal harmonic functions and Fétis's description of culture-specific, scale-based effects of tension and repose (Dahlhaus, 1967/1990). Krumhansl's *Cognitive Foundations of Musical Pitch* has much to say on these issues, and I urge anyone who is seriously concerned with how people hear music to read it.

Robert O. Gjerdingen

SUNY at Stony Brook

References

- Bharucha, J. J. Anchoring effects in music: The resolution of dissonance. *Cognitive Psychology*, 1984, 16, 485–518.
- Bourdieu, P. *Outline of a theory of practice* (R. Nice, Trans.). (Originally published 1972 as *Esquisse d'une theorie de la pratique, precede de trois etudes d'etnologie kabyle*.) Cambridge: Cambridge University Press, 1977 [Cambridge Series in Social Anthropology, No. 16].
- Budge, H. *A study of chord frequencies*. New York: Bureau of Publications, Teachers College, Columbia University, 1943.
- Butler, D. Describing the perception of tonality in music: A critique of the tonal hierarchy theory and a proposal for a theory of intervallic rivalry. *Music Perception*, 1989, 6, 219–242.
- Buder, D. Response to Carol Krumhansl. *Music Perception*, 1990, 7, 309–324.
- Castil-Blaze, s.v. *Tonalité*. In *Dictionnaire de musique moderne*. Paris: Au magasin de musique de la Lyre moderne, 1821.
- Dahlhaus, C. *Studies on the origin of harmonic tonality* (R. O. Gjerdingen, Trans.). (Originally published 1967 as *Untersuchungen über die Entstehung der harmonischen Tonalität*.) Princeton, NJ: Princeton University Press, 1990.
- Deutsch, D., & Feroe, J. The internal representation of pitch sequences in tonal music. *Psychological Review*, 1981, 88, 503–522.
- Gjerdingen, R. O. Meter as a mode of attending: A network simulation of attentional rhythmicity in music. *Integral*, 1989, 3, 67–91.

- Hughes, M. A quantitative analysis. In M. Yeston (Ed.), *Readings in Schenker analysis and other approaches*. New Haven, CT: Yale University Press, 1977.
- Knopoff, L., & Hutchinson, W. Entropy as a measure of style: The influence of sample length. *Journal of Music Theory*, 1983, 27, 75–97.
- Krumhansl, C. L. Tonal hierarchies and rare intervals in music cognition. *Music Perception*, 1990, 7, 309–324.
- Krumhansl, C. L., & Kessler, E. J. Tracing the dynamic changes in perceived tonal organization in a spatial representation of musical keys. *Psychological Review*, 1982, 89, 334–368.
- Krumhansl, C. L., & Shepard, R. N. Quantification of the hierarchy of tonal functions within a diatonic context. *Journal of Experimental Psychology: Human Perception and Performance*, 1979, 5, 579–594.
- Janara, P., & Reisberg, D. Response-time measures as a means of exploring tonal hierarchies. *Music Perception*, 1988, 6, 161–172.
- Lerdahl, F. Tonal pitch space. *Music Perception*, 1988, 5, 315–350.
- Narmour, E. *The analysis and cognition of basic melodic structures: The implication-realization model*. Chicago: University of Chicago Press, 1990.
- Parncutt, R. Sensory bases of harmony in Western music. Unpublished doctoral dissertation, University of New England, Australia, 1987.
- Parncutt, R. Revision of Terhardt's psychoacoustical model of the root(s) of a musical chord. *Music Perception*, 1988, 6, 65–94.
- Sadai, Y. Die Grundlagen einer systemischen Theorie der tonalen Musik. *Musiktheorie*, 1990, 5, 137–160.
- Terhardt, E., Stoll, G., & Seewan, M. Pitch of complex signals according to virtual-pitch theory: Tests, examples, and predictions. *Journal of the Acoustical Society of America*, 1982a, 71, 671–678.
- Terhardt, E., Stoll, G., & Seewan, M. Algorithm for extraction of pitch and pitch salience from complex tonal signals. *Journal of the Acoustical Society of America*, 1982b, 71, 679–688.
- Tversky, A., & Hutchinson, J. W. Nearest neighbor analysis of psychological spaces. *Psychological Review*, 1986, 93, 3–22.
- West, R. J., & Fryer, R. Ratings of suitability of probe tones as tonics after random orderings of notes of the diatonic scale. *Music Perception*, 1990, 7, 253–258.
- Youngblood, J. E. Style as information. *Journal of Music Theory*, 1958, 93, 2–49.